# Early Detection and Population Monitoring of *Ceratitis capitata* (Diptera: Tephritidae) in a Mixed-Fruit Orchard in Northern Greece

NIKOS T. PAPADOPOULOS,[1] BYRON I. KATSOYANNOS,[1, 2] NIKOS A. KOULOUSSIS,[1] JORGE HENDRICHS,[3] JAMES R. CAREY,[4] AND ROBERT R. HEATH[5]

Laboratory of Applied Zoology and Parasitology, Department of Agriculture, University of Thessaloniki, 540 06 Thessaloniki, Greece

J. Econ. Entomol. 94(4): 971–978 (2001)

**ABSTRACT** Population monitoring of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), was studied in 1998 in a mixed-fruit orchard in northern Greece, using International Pheromone McPhail traps (IPMT) baited with the female targeted attractants ammonium acetate, putrescine, and trimethylamine, and Jackson traps baited with the male specific parapheromone trimedlure. Special emphasis was placed on detecting the low initial adult population resulting from surviving overwintering larvae as early as possible in the spring and early summer. Traps were suspended on various host trees, using trap grid densities of either 15 or 1.5 traps per hectare. The first adults detected were females captured on 24 June in IPMT traps suspended on apricot trees, which are among the earliest maturing hosts in the area. From the end of July, the most effective trap was the IPMT trap placed on peaches, which followed apricots in the fruit ripening sequence. IPMT traps captured predominately females (≈80% of the total captures) and by far outperformed Jackson traps in early detection (the first males in Jackson traps were captured in August) as well as in total captures until mid-October. After mid-October, however, more flies were captured in Jackson traps. Comparing the performance of two trap grid densities on apple trees (the common host in the two grids), we found that in the high-density trap grid the first adults were detected 1 wk earlier than in the low-density trap grid. Our findings for this locality suggest that trap type and plant species on which traps are suspended are of key importance in early detection and population monitoring of *C. capitata.*

**KEY WORDS** *Ceratitis capitata*, early detection, trapping, hosts, food attractants

THE MEDITERRANEAN FRUIT fly, *Ceratitis capitata* (Wiedemann), is one of the most serious pests worldwide, infesting fruits of >300 plant species (Liquido et al. 1991). The sterile insect technique (Hendrichs et al. 1995) and other important methods for controlling or eradicating this insect are most effective when applied against small target populations. Therefore, timely detection of small populations helps management of this pest considerably (Dowell et al. 1999). Unfortunately, recent studies have demonstrated early detection to be rather difficult (Papadopoulos et al. 2000). At least in temperate areas, emerging adults from small populations may remain unnoticed for long periods after emergence, even by trap systems generally regarded as highly effective (Papadopoulos 1999).

Studies on the population dynamics of *C. capitata* have shown that the main factor affecting population buildup in the tropics is fruit abundance and availability, whereas in temperate areas low winter temperatures also play a major role (Rivnay 1951, Harris 1975, Vargas et al. 1983, Nishida et al. 1985, Fimiani 1989, Eskafi and Kolbe 1990, Michelakis 1992, Cayol and Causse 1993, Harris et al. 1993, Israely et al. 1997, Katsoyannos et al. 1998, Papadopoulos 1999). In the colder temperate parts of *C. capitata* distribution, such as in northern Greece, most of the population dies during winter. However, a small percentage of the population survives the low temperatures as larvae, overwintering within the fruits into which they were deposited as eggs the previous autumn. From these larvae, a very small adult population develops by the end of March or beginning of April. Adults from this population are usually not captured in traps for approximately 3 mo, depending on the trap type used and other factors such as trap grid density and host trees on which traps are installed. These adults oviposit in early maturing hosts in late May or June (Papadopoulos et al. 1996, 1998, 2000).

Population monitoring and detection of *C. capitata* is mostly based on trapping with either Jackson traps baited with the male specific parapheromone

[1] Laboratory of Applied Zoology and Parasitology, Department of Agriculture, University of Thessaloniki, 540 06 Thessaloniki, Greece.
[2] To whom reprint requests should be addressed.
[3] Insect and Pest Control Section, International Atomic Energy Agency, P.O. Box 100, A-1040 Vienna, Austria.
[4] Department of Entomology, University of California, Davis, CA 95616.
[5] Center for Medical, Agricultural and Veterinary Entomology, USDA-ARS, Gainesville, FL 32604.

trimedlure (*tetr*-butyl-4-[and 5]-chloro-2-methylcyclohexane-1-carboxylate) (Beroza et al. 1961) or McPhail trap types baited with an aqueous solution of protein hydrolysate (usually NuLure, Miller Chemicals and Fertilizer, Hanover, PA) plus borax as preservative (Katsoyannos 1994, Heath et al. 1997). Population monitoring is also based on fruit sampling (Harris et al. 1988, Katsoyannos et al. 1998, Papadopoulos 1999).

During the last few years, an effective female-targeted trapping system consisting of a McPhail trap baited with three food-based, synergistically acting attractants (ammonium acetate, putrescine, and trimethylamine) was developed (Heath et al. 1997; Katsoyannos et al. 1999a, 1999b). This system outperforms Jackson traps in total captures and is more selective and practical to use than traps employing aqueous protein solutions (Katsoyannos et al. 1999a, 1999b). However, there is no published information on the performance of this trapping system throughout the season and on its sensitivity in detecting small populations, such as early season populations in temperate areas.

The main objective of this study was to compare the performance of the conventional Jackson trap with the performance of the triple-baited McPhail trap in monitoring *C. capitata* in a mixed-fruit orchard in northern Greece. Emphasis was placed on observing differences between the two trap systems in detecting the very low spring and summer population of the fly in this area. The effects of the host species on which traps were suspended and of the density of traps in an orchard on early detection of *C. capitata* were also studied.

## Materials and Methods

The study was conducted during 1998 on the Aristotle University of Thessaloniki farm (40.3° northern latitude; sea level) in northern Greece. Ten out of 200 ha total surface area of the farm were occupied by pome fruits, stone fruits, and a few other hosts (Fig. 1). In particular, apples (*Malus sylvestris* Mill.) occupied 5 ha; pears (*Pyrus communis* L.) occupied 0.7 ha; apricots (*Prunus armeniaca* L.), peaches [*P. persica* (L.) Batsch], cherries (*P. avium* L.), sour cherries (*P. cerasus* L.), and plums [*P. domestica* (L.)] occupied a total of ≈0.9 ha; walnuts (*Juglans regia* L.) occupied 0.4 ha; kiwis (*Actinidia chinensis* Planch.) occupied 0.9 ha; and olives (*Olea europaea* L.) occupied 0.6 ha. There were also ≈20 figs (*Ficus carica* L.), five oriental persimmons (*Diospyros kaki* L.), 10 quinces (*Cydonia oblonga* Mill.), and three loquats [*Eriobotrya japonica* (Thounb.)] planted on the edges of the orchard. Cherries and loquats mature first in the experimental farm at the end of May, followed by apricots in June and peaches in July (Fig. 2). Pears mature in mid-August, figs in late August, apples in September and October, and oriental persimmons in October and November (Papadopoulos 1999).

Meteorological data provided by a station located 500 m northeast of the experimental farm showed that the mean monthly temperature ranged between 21.4 and 28.8°C from June to September, and dropped to 17.4, 11.0, and 3.5°C in October, November, and December, respectively. Daily temperatures ranged between 12 and 42°C from June to September, 3 and 28°C in October, −4 and 25°C in November, and −6 and 18°C in December.

*Ceratitis capitata* adults were monitored using the Jackson trap baited with trimedlure (AgriSence, Fresno, CA) and the International Pheromone McPhail Trap (IPMT, International Pheromone Systems, South Wirral, England) baited with three dispensers loaded with the synergistically acting

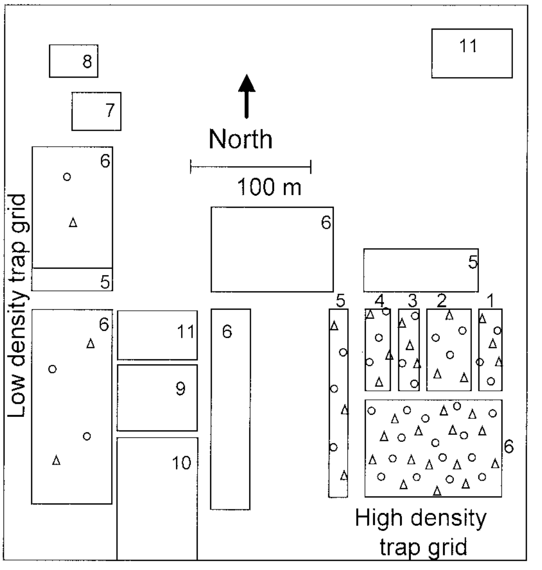


**Fig. 1.** Location of traps in the experimental orchards (circles, IPMT traps; triangles, Jackson traps). The numbers indicate the species of host trees (1 = apricots, 2 = peaches, 3 = plums, 4 = cherries, 5 = pears, 6 = apples, 7 = figs, 8 = oriental persimmons, 9 = walnuts, 10 = kiwis, 11 = olives).

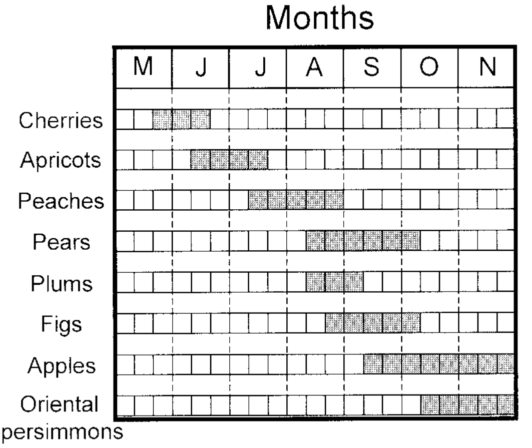


**Fig. 2.** Ripening periods (shaded areas) of the principal host trees of *C. capitata* in the experimental farm.

attractants, ammonium acetate, putrescine, and trimethylamine (Biolure, Consept, Bend, OR). To capture the attracted flies, 300 ml water with 0.01% of the surfactant Triton (Union Carbide, Danbury, CT) were added to the lower part of the IPMT trap (Katsoyannos et al. 1999a). During June, we observed decomposition of the captured insects that dropped in the water. To prevent decomposition, from July onwards a 10% water solution of an automobile antifreeze containing ≈40% ethylene glycol was used in place of water and surfactant (unpublished data).

In one part of the orchard (2 ha in total) composed of 0.9 ha stone fruit trees, 0.9 ha 'Granny Smith' and a few 'Golden Delicious' apple trees, and 0.2 ha 'Nashi' pear trees, we installed 30 Jackson and 30 IPMT traps at a density of 15 traps of each type per hectare (high-density trap grid). Traps were placed ≈10–15 m apart, with one trap of each type per tree row. Three pairs of traps were placed in apricots, peaches, plums, cherries, and pears, and 15 pairs were placed in apples (Fig. 1). In another part of the orchard composed of 1.8 ha apples (mainly Golden Delicious, but also Granny Smith and 'Red Delicious') and 0.2 ha pears, we placed three pairs of traps at a density of ≈1.5 traps of each type per hectare (low-density trap grid).

The traps were installed on 6 April 1998, based on past studies that have shown that emergence of adults in this area begins early in April (Papadopoulos et al. 1996). All traps were placed 1.5–1.8 m above the ground in the tree canopy. At the time of trap installation, most of the trees in the experimental orchard were in blossom. Traps were serviced once a week until the end of December, and the captured *C. capitata* adults were counted and removed. The liquid in the lower part of the IPMT traps was replaced every week, and the attractant dispensers were replaced every month. The trimedlure dispenser in Jackson traps was replaced every 3 wk.

In an attempt to relate trapping data with fruit infestation rates, ripening or ripe fruits, which mature early in the season, such as loquats and apricots, were inspected on trees for *C. capitata* infestation. Those fruits showing symptoms of infestation (possible oviposition stings or small discoloration on the fruit surface) were removed from trees, carefully opened with a razor blade, and examined for eggs or larvae. Examination was conducted either in the field using a hand lens or in the laboratory using a stereomicroscope. We also collected small samples of ripe and semiripe fruits from the trees and from the ground throughout the trapping period to determine infestation by incubation of samples. Fruits were placed in plastic containers on a 3-cm layer of dry sand, maintained at 25 ± 2°C in the laboratory, and checked once a week (collecting and counting emerging larvae and pupae by sieving the sand) for ≈1.5 mo (six to seven checks) for mature larvae and pupae.

**Statistical Analysis.** Trap counts were transformed to $\ln(x + 1)$ to homogenize variances. The effects of trap type and host tree on which traps had been installed on *C. capitata* catches were analyzed by repeated measures analysis of variance (ANOVA) (SPSS 1997). Weekly captures from 24 June to 24 November (23 counts) were considered as the repeated factor. Because the interaction between week of trap checking and trap type was significant, we used the Student's *t*-test to compare the mean number of adults captured each week in Jackson traps with that of IPMT traps. The effects of grid density on *C. capitata* catches were analyzed by repeated measures ANOVA on data [ln(catches + 1)] derived only from traps placed on apples (the common host in two grids). Weekly captures from 7 July to 26 November (21 counts) were considered as the repeated factor. The effect of host tree on which traps had been installed on the proportion of females (females/[males + females]) captured was analyzed by repeated measures ANOVA on the data of IPMT traps. Because the number of IPMT traps that captured insects was very small (≤30%) until the beginning of September, only the weekly data from 9 September to 18 November (11 counts) were considered as the repeated factor. The percentages of IPMT and Jackson traps that captured at least one fly were compared for each week of trapping using the chi-square test (Sokal and Rohlf 1995).

## Results

In the high-density trap grid, the IPMT traps captured a total of 7,196 *C. capitata* adults, and the Jackson traps 7,930 adults. In the low-density trap grid, the IPMT traps captured a total of 2,450 adults, and the Jackson traps 3,051 adults. These numbers correspond to a mean number of 239.9 ± 22.4 (mean ± SE) and 816.7 ± 119.8 flies per trap in IPMT traps for the high and the low-density trap grid respectively, and a mean number of 264.3 ± 29.8 and 1,017.0 ± 173.6 flies in the Jackson traps for the two grids, respectively.

In both trap grids, IPMT traps captured more females than males throughout the season, whereas Jackson traps captured exclusively males. In the high-density trap grid, IPMT traps captured 5,542 females and 1,654 males (female to male ratio 3.4, or 77% females). In the low-density trap grid, they captured 2,102 females and 348 males (female to male ratio 6.0, or 85.7% females). Statistical analysis showed a significant effect of the host trees on which traps had been placed and of the week of trap check on the proportion of females captured ($F = 7.8$; df = 5, 19; $P < 0.01$ and $F = 8.1$; df = 10, 190; $P < 0.01$, respectively). Interaction between host trees and week of trap check ($F = 2.6$; df = 50, 190; $P < 0.01$) indicates changes in the proportion of females captured in different host trees in relation to the time of the season. The percentage of females captured in IPMT traps increased from 63.3% on 9 September to 90% on 14 October, and it decreased again toward the end of the season, reaching 64% on 18 November.

Trap type and host species had a significant effect on overall number of *C. capitata* captures (Table 1). Interaction between trap type and week of trap check indicates that the performance of the two traps differs in relationship to the time of the season. Interaction

**Table 1. Repeated measures analysis of variance (23 weekly counts made from 24 June to 24 November) of *C. capitata* in Jackson or IPMT traps (first factor, trap type) suspended on apricots, peaches, or other trees (second factor, host tree)**

| Source of variation | Sum of squares | $F$ | df | $P$ |
|---|---|---|---|---|
| Trap (trap type) | 11.7 | 9.5 | 1 | <0.01 |
| Host tree (tree species) | 44.5 | 7.2 | 5 | <0.01 |
| Trap × host tree | 18.8 | 3.1 | 5 | 0.02 |
| Error (between subjects) | 59.5 | | 48 | |
| Week (week of traps check) | 1518.6 | 317.9 | 22 | <0.01 |
| Week × trap | 251.1 | 11.4 | 22 | <0.01 |
| Week × host tree | 99.3 | 4.2 | 110 | <0.01 |
| Week × trap × host tree | 53.9 | 2.3 | 45 | <0.01 |
| Error (Weeks) | 229.2 | | 1,056 | |

Data were transformed to $\ln(x+1)$ before analysis.

between host and week indicates the importance of trap placement for early detection of the fly.

With regard to trap density, we compared the two grids considering only those traps placed on apples because the role of host trees on which traps had been placed was shown to be significant (Table 1). Grid density had a significant effect on the number of adults captured ($F = 58.5$; df = 1, 32; $P < 0.01$); whereas trap type did not ($F = 1.4$; df = 1, 32; $P = 0.24$). Interaction between trap type and grid density ($F = 5.6$; df = 1, 32; $P = 0.02$) indicates that the performance of the two traps differed in relation to the density in which they were deployed. Interaction between grid density and week of trap check ($F = 9.7$, df = 20.7, $P < 0.01$) indicates that the performance of the two grids changed over the season.

The first adult (a female) was detected on 24 June in the high-density trap grid in an IPMT trap placed in an apricot tree (Fig. 3). This was about 3 wk earlier than the first captures in traps placed on any other tree species. Up to 22 July, traps placed in apricot trees captured at least three times more insects than traps placed on other trees. From the end of July until the end of August, the IPMT traps placed in peach trees, which followed apricots in ripening sequence, were the most effective. In sharp contrast to IPMT traps, Jackson traps placed in the high-density trap grid in apricot trees did not capture any adults early in the season. The first adult in a Jackson trap was detected on 5 August (≈1.5 mo later than in IPMT traps) in a trap placed in an apple tree located close to the peach trees.

In apples, the primary common host in the two parts of the orchard where the two grids were deployed (Fig. 1), the first adults were captured in the high-density trap grid only one week earlier than in the low-density trap grid (Fig. 4). In both grids, the first adults were detected in IPMT traps, whereas the first adults in Jackson traps were captured 1–1.5 mo later.

The percentage of traps that captured at least one fly in each trap check in relation to the time of the season in the high-density trap grid is given in Fig. 5. Approximately 10–30% of the IPMT traps captured adults from the end of July until the end of August. This percentage increased to 76.7% on 2 September

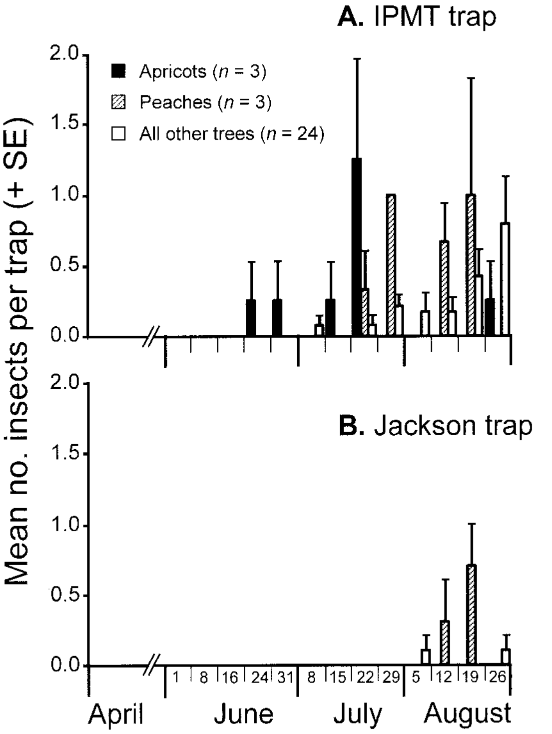


**Fig. 3.** Early and midseason captures of *C. capitata* in (A) IPMT and (B) Jackson traps placed on different hosts in the high-density trap grid (15 traps of each type per hectare, $n$ = number of traps on each host).

and to >90% from 9 September onward. Less than 10% of Jackson traps captured adults during August, but this percentage progressively increased to 80% on 30 September and to 100% in October and November. The percentage of IPMT traps capturing adults was significantly higher than that of Jackson traps in most of the trap checks from 22 July to 30 September ($\chi^2 > 3.2$, df = 1, $P < 0.05$). These results indicate a progressive dispersion of the population from the early maturing hosts at the beginning of the season (captures only in traps placed on these hosts), to the entire orchard later on. Also, it demonstrates that when the population is low and localized, IPMT traps are much more sensitive than Jackson traps in detecting adults.

IPMT traps performed better than Jackson traps early in the season and up to the beginning of October (Fig. 6). In the high-density trap grid (Fig. 6A), IPMT traps captured significantly more adults than Jackson traps in most of the trap checks from 22 July until the first week of October ($t > 2.1$, df = 58, $P < 0.05$). A shift in trap performance was observed from the middle of October, when Jackson traps started capturing significantly more flies than IPMT traps ($t = 1.2$, df = 58, $P = 0.22$ on 14 October; and $t > 2.1$, df = 58, $P < 0.05$ from 21 October to the end of November). The same trends in population fluctuation and statistics were found in both trap grids when considering only those traps placed in apple trees (Fig. 6 B and C).

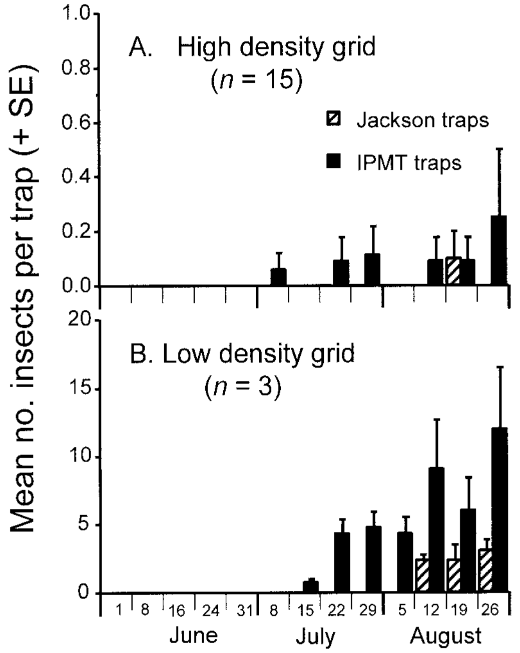


Fig. 4. Early and midseason captures of *C. capitata* in IPMT and Jackson traps set out in (A) high-density (15 traps of each trap per ha) and (B) low-density trap grids (1.5 traps of each type per hectare). In both grids only those traps placed in apples were considered ($n$ = the number of traps of each type used).

Visual inspections of fruits early in the season failed to identify any *C. capitata* infestation. Out of 120 loquats and 276 apricots examined, 29 and 42, respectively, displayed some infestation symptoms and were opened with a razor. However, no immatures were found. With regard to fruit sampling, in June we collected 16 loquats, 156 apricots, 200 cherries, and 325 sour cherries; in July, 106 apricots and 10 peaches; in August, 17 peaches and 27 pears; in September, 67 figs, 24 apples, and 36 pears. The first fruits that yielded larvae in the laboratory were figs (4.3 larvae per fruit), which were collected at the beginning of September. Later in autumn, high infestation levels (5–10 larvae per fruit) were recorded in apples, pears, and oriental persimmons (850, 210, and 55 fruits collected, respectively).

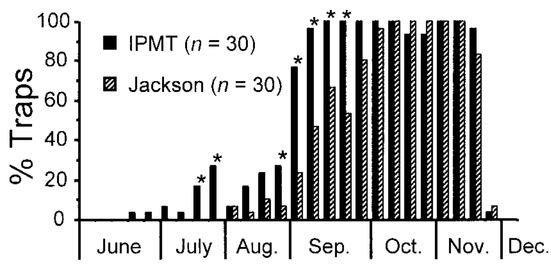


Fig. 5. Percentage of Jackson and IPMT traps in the high-density trap grid that captured *C. capitata* adults in relation to the time of the year. Asterisks above bars indicate significant differences between the two traps ($\chi^2$, $P < 0.05$) ($n$ = the number of traps of each type used).

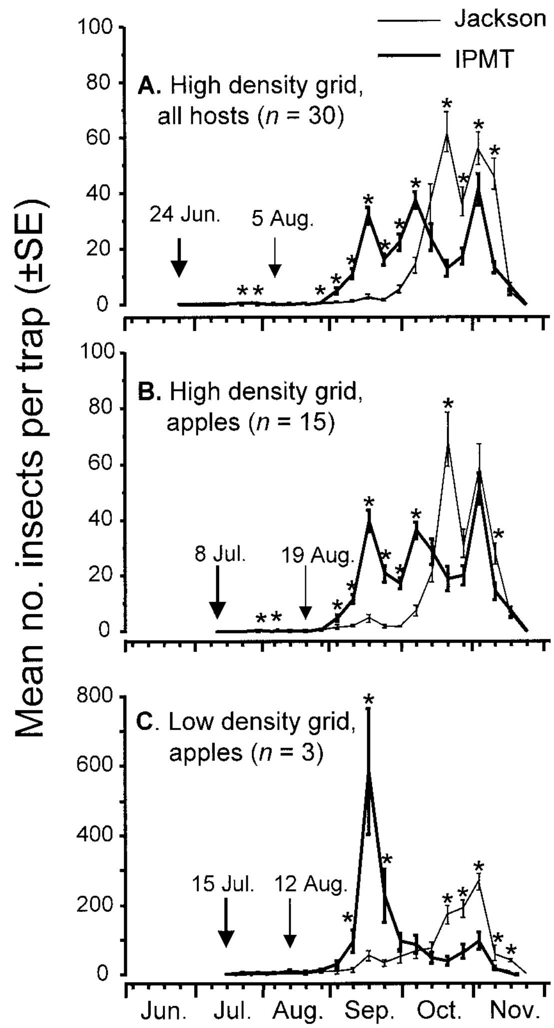


Fig. 6. Seasonality of *C. capitata* captures in Jackson and IPMT traps placed on different hosts. (A) High-density trap grid (15 traps of each type per hectare) with all hosts considered. (B) High-density trap grid only apples considered. (C) Low-density grid of 1.5 traps of each type per ha placed in apple trees. Arrows indicate the date of first adult detection ($n$ = the number of traps of each type used). Asterisks above standard error bars indicate significant differences between the two traps ($t$-test, $P < 0.05$).

## Discussion

IPMT traps baited with the three food lures (ammonium acetate, putrescine, and trimethylamine) outperformed the trimedlure-baited Jackson trap in total captures during most of the period of *C. capitata* adult activity in northern Greece. In particular, IPMT traps were most effective from the end of June until mid-October, at fly population densities that were initially very low and then progressively grew very high. As shown in previous studies (Heath et al. 1997; Katsoyannos et al. 1999a, 1999b), IPMT traps captured mostly females, whereas Jackson traps captured exclusively males. From mid-October onward, however, trap efficacy shifted in favor of the Jackson trap. Changes in the sex ratio of the population over the season may in part account for this shift, given the distinctive difference in sex specificity between the two traps. Another possible reason for the observed shift in trap performance may be that adults' response to the attractants varies over the season. This varying response may in turn be due to changes in adult physiology or the emission rates of the attractants (Jones 1988) resulting from the decrease in temperature and increase in relative humidity toward autumn.

The proportion of females captured in IPMT traps was higher than that of males throughout the season. Moreover, there was a significant further increase in female-biased captures toward October, which may be explained by several reasons. One reason is that female or male response to food lures in the IPMT trap or to the entire trap may vary over the season. Another is that the very high rates of male captures in Jackson traps reported in October might have removed a high proportion of males from the orchard, thus influencing sex ratio of adults responding to IPMT traps. Still another possible reason is that large numbers of females might have moved to the study orchards from neighboring orchards in search of oviposition sites after the harvest of fruits, thus affecting the sex ratio of adults captured.

In both trap grids, IPMT traps detected the early-season adult population ≈1.5 mo earlier than did Jackson traps. This shows the importance of trap type in early detection of this fly. The host species on which traps are suspended is also important in early detection. In the study area, the first adults of the season probably emerged in apple orchards, given that in this area the fly has been shown to overwinter as larvae within apples attacked in late autumn (Papadopoulos 1999). Nevertheless, the first captures were recorded in traps placed in apricot trees and not apple trees. The key host for early detection was therefore apricot, which matures earlier than other (potential) hosts in the area and produces fruits that coincide (based on our estimations) temporally with the presence of gravid females. Hence, to increase trap efficiency in early detection of the fly under conditions of low population densities, the key early maturing hosts should be carefully pinpointed and pertinent protocols for trap deployment devised. Lance and Gates (1994) have suggested that traps should be placed on or near host trees bearing ripe or semiripe fruits. The importance of apricots for breeding the first summer generation of *C. capitata* in other areas of Greece, such as the island of Chios, is discussed in Katsoyannos et al. (1998).

Our results suggest that in areas with conditions similar to those of Thessaloniki, early in the season low populations of adults are concentrated around hosts that bear fruits suitable for oviposition. As these resources become exhausted and the fly population increases, adults spread and their distribution within an area becomes progressively more uniform. Bateman (1972), Israely et al. (1997), Katsoyannos et al. (1998), and Papadopoulos (1999) have also reported similar trends.

Comparison of captures in the two trap grids (1.5 versus 15 traps per hectare) for traps suspended only in apple trees (late maturing hosts) indicated that grid density had little effect in early detection in this host. Unavailability of large orchards with early maturing hosts in the area prohibited us from conducting experiments in these hosts to study the effect of trap grid density in early detection. Such experiments could provide more precise information related to the optimum trap grid density for early detection. Several studies examining dispersal and trap sensitivity in relation to trap grid density of *C. capitata* have been conducted using the release-recapture method (Wong et al. 1982; Cunningham and Couey 1986; Baker and Chan 1991a, 1999b; Lance and Gates 1994). As estimated by Lance and Gates (1994), a grid of 1,000 trimedlure baited panel traps per 2.6 $km^2$ (≈1.5 trap per ha) would always capture one or more flies when there are at least 10 males in the area. However, in the study by Lance and Gates (1994) and in similar studies, the effect of host trees on trap sensitivity was not considered. Moreover, in all but one (Wong et al. 1982) of the above studies, laboratory reared, sterilized flies were used. Behavioral differences between flies of laboratory strains and wild flies, sterilization of the released flies, the possible abnormal behavior of flies immediately after release, and environmental factors may limit the applicability of the results of these studies (Lance and Gates 1994).

Besides trapping, fruit sampling or fruit inspection has been proposed and practiced as an alternative or supplementary method for early detection of *C. capitata* populations (Papadopoulos 1999, Papadopoulos et al. 2000). In previous studies that we conducted in the same orchard, sampling apricots (and, later in the season, peaches) and incubating them in the laboratory yielded the first pupae at the end of June. This detection of immatures almost coincided with the first captures of adults in traps (Papadopoulos 1999, Papadopoulos et al. 2000). Failure in the current study to detect immatures of the fly by fruit inspection and sampling is probably due to the fact that in the previous autumn most of the fallen infested apples (overwintering refugia) in the experimental orchard had been collected and destroyed as a phytosanitary measure against *C. capitata.* Consequently, the initial population was apparently much lower than that of the previous years and the infestation of apricots was too low to be detected by the limited fruit sampling we performed. Random and undirected fruit sampling was also found to be ineffective in detecting *C. capitata* larvae and was discontinued in California in 1997 (Dowell et al. 1999). Furthermore, extensive fruit sampling is needed to detect very low infestations. This fruit sampling, apart from being laborious and costly, could also reduce the fruit yield, especially in small orchards.

## Acknowledgments

We thank E. Manolakis (University Farm, Department of Agriculture, Aristotle University of Thessaloniki) for allowing us to conduct the experiments on the farm, and Fotis Kaderidis and Nikos Kaderidis for technical assistance. This work was supported by the International Atomic Energy Agency (grant 7651/RB) and the California Citrus Research Board.

## References Cited

**Baker, P. S., and A.S.T. Chan. 1991a.** Quantification of tephritid fruit fly dispersal: guidelines for a sterile release programme. J. Appl. Entomol. 112: 410–421.

**Baker, P. S., and A.S.T. Chan. 1991b.** Appetitive dispersal of sterile fruit flies: methodology and analysis of trapping studies. J. Appl. Entomol. 112: 263–273.

**Bateman, M. A. 1972.** The ecology of fruit flies. Annu. Rev. Entomol. 17: 493–518.

**Beroza, M., N. Green, S. I. Geltler, L. F. Steiner, and D. H. Miyashita. 1961.** Insect attractants: new attractants for the Mediterranean fruit fly. J. Agric. Food Chem. 9: 361–365.

**Cayol, J. P., and R. Causse. 1993.** Mediterranean fruit fly *Ceratitis capitata* Wiedemann (Dipt., Trypetidae) back in southern France. J. Appl. Entomol. 116: 94–100.

**Cunningham, R. T., and H. M. Couey. 1986.** Mediterranean fruit fly (Diptera: Tephritidae): distance/response curves to trimedlure to measure trapping efficiency. Environ. Entomol. 15: 71–74.

**Dowell, R. V., I. A. Siddiqui, F. Meyer, and E. L. Spaugy. 1999.** Early results suggest sterile flies may protect S. California from medfly. Calif. Agric. 53: 28–32.

**Eskafi, F. M., and M. E. Kolbe. 1990.** Infestation patterns of commonly cultivated, edible fruit species by *Ceratitis capitata* and *Anastrepha* spp. (Diptera: Tephritidae) in Guatemala and their relationship to environmental factors. Environ. Entomol. 19: 1371–1380.

**Fimiani, P. 1989.** Mediterranean region, pp. 39–50. *In* A. S. Robinson and G. Hooper [eds.], Fruit flies: their biology, natural enemies and control. World crop pests, vol. 3A. Elsevier, Amsterdam.

**Harris, E. J. 1975.** Biotic factors influencing population trends of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), in selected host habitats in Tunisia. Ph.D. dissertation, University of Hawaii, Honolulu.

**Harris, E. J., C. Ford-Livene, and C.Y.L. Lee. 1988.** Population monitoring of tephritid fruit flies by stratified sampling on the island of Oahu, Hawaii, pp. 342–352. *In* S. Vijaysegaran and A. G. Ibrahim [eds.], Proceedings, Symposium: Fruit flies in the Tropics. International Symposium, 14–16 March 1988, Kuala Lumpur, Malaysia. Malaysian Research and Development Institute (MARDI), Kuala Lumpur, Malaysia.

**Harris, E. J., R. I. Vargas, and J. E. Gilmore. 1993.** Seasonality in occurrence and distribution of Mediterranean fruit fly (Diptera: Tephritidae) in upland and lowland areas on Kauai, Hawaii. Environ. Entomol. 22: 404–410.

**Heath, R. R., N. D. Epsky, B. D. Dueben, J. Rizzo, and F. Jeronimo. 1997.** Adding methyl-substituted ammonia derivates to a food-based synthetic attractant on capture of the Mediterranean and Mexican fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 90: 1584–1589.

**Hendrichs, J., G. Franz, and P. Rendon. 1995.** Increased effectiveness and applicability of the sterile insect technique through male-only releases for the control of the Mediterranean fruit flies during fruiting season. J. Appl. Entomol. 119: 371–377.

**[IAEA] International Atomic Energy Agency. 1999.** Development of female medfly attractant systems for trapping and sterility assessment. TECDOC 1099. IAEA, Vienna Austria.

**Israely, N., B. Yuval, U. Kitron, and D. Nestel. 1997.** Population fluctuations of adult Mediterranean fruit flies (Diptera: Tephritidae) in a Mediterranean heterogeneous agricultural region. Environ. Entomol. 26: 1263–1269.

**Jones, V. P. 1988.** Longevity of apple maggot (Diptera: Tephritidae) lures under laboratory and field conditions in Utah. Environ. Entomol. 17: 704–708.

**Katsoyannos, B. I. 1994.** Evaluation of Mediterranean fruit-fly traps for use in sterile-insect-technique programmes. J. Appl. Entomol. 118: 442–452.

**Katsoyannos, B. I., N. A. Kouloussis, and J. R. Carey. 1998.** Seasonal and annual occurrence of Mediterranean fruit flies (Diptera: Tephritidae) on Chios island, Greece: differences between two neighboring citrus orchards. Ann. Entomol. Soc. Am. 91: 43–51.

**Katsoyannos, B. I., R. R. Heath, N. T. Papadopoulos, N. D. Epsky, and J. Hendrichs. 1999a.** Field evaluation of Mediterranean fruit fly (Diptera: Tephritidae) female selective attractants for use in monitoring programs. J. Econ. Entomol. 92: 583–589.

**Katsoyannos, B. I., N. T. Papadopoulos, R. R. Heath, J. Hendrichs, and N. A. Kouloussis. 1999b.** Evaluation of synthetic food-based attractants for female Mediterranean fruit flies (Dip., Tephritidae) in McPhail type traps. J. Appl. Entomol. 123: 607–612.

**Lance, D. R., and D. B. Gates. 1994.** Sensitivity of detection trapping systems for Mediterranean fruit flies (Diptera: Tephritidae) in southern California. J. Econ. Entomol. 87: 1377–1383.

**Liquido, N. J., L. A. Shinoda, and R. T. Cunningham. 1991.** Host plants of the Mediterranean fruit fly (Diptera: Tephritidae): an annotated world review. Miscellaneous Publication 77. Entomological Society of America, Lanham, MD.

**Michelakis, S. E. 1992.** Phenology of the Mediterranean fruit fly *Ceratitis capitata* Wiedemann in Crete. Israel J. Entomol. 25–26: 177–180.

**Nishida, T., E. Harris, R. I. Vargas, and T.T.Y. Wong. 1985.** Distributional and host fruit utilization patterns of the Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae), in Hawaii. Environ. Entomol. 14: 602–608.

**Papadopoulos, N. T. 1999.** Study on the biology and ecology of the Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae) in northern Greece. Ph.D. dissertation, Aristotle University of Thessaloniki, Thessaloniki, Greece.

**Papadopoulos, N. T., J. R. Carey, B. I. Katsoyannos, and N. A. Kouloussis. 1996.** Overwintering of *Ceratitis capitata* (Diptera: Tephritidae) in northern Greece. Ann. Entomol. Soc. Am. 89: 526–534.

**Papadopoulos, N. T., B. I. Katsoyannos, and J. R. Carey. 1998.** Temporal changes in the composition of the overwintering larvae population of the Mediterranean fruit fly (Diptera: Tephritidae) in northern Greece Ann. Entomol. Soc. Am. 91: 430–434.

**Papadopoulos, N. T., B. I. Katsoyannos, and J. R. Carey. 2000.** Spring and early summer phenology of *Ceratitis capitata* (Diptera: Tephritidae) in northern Greece, pp. 583–590.

*In* K. H. Tan [ed.], Area wide control of fruit flies and other insect pests. CAB Wallingford, UK.

**Rivnay, E. 1951.** The Mediterranean fruit fly in Israel. Bull. Entomol. Res. 41: 321–341.

**Sokal, R. R., and F. J. Rohlf. 1995.** Biometry, 3rd ed. Freedman, New York.

**SPSS. 1997.** SPSS for Windows, User's guide, version 8.0. SPSS, Chicago IL.

**Vargas, R. I., E. J. Harris, and T. Nishida. 1983.** Distribution and seasonal occurrence of *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) on the island of Kauai in the Hawaiian islands. Environ. Entomol. 12: 303–310.

**Wong, T.T.Y., L. C. Whitehand, R. M. Kobayashi, K. Ohinata, N. Tanaka, and E. J. Harris. 1982.** Mediterranean fruit fly: dispersal of wild and irradiated and untreated laboratory-reared males. Environ. Entomol. 11: 339–343.

*Received for publication 6 June 2000; accepted 9 December 2000.*